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TECHNICAL REPORT

ASWEPS REPORT NO. 12

HEAT ABSORPTION AND HEAT BUDGET AT OCEAN STATION ECHO, SEPTEMBER 1959

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ABSTRACT

Between 2 and 21 September 1959, approximately 900 bathythermograph observations (BT's) were obtained at Ocean Weather Station ECHO (35° N, 48° W). In addition, incoming radiation from sun and sky and reflected radiation from the sea surface were recorded. By grouping the BT data according to cloud amount, mean hourly temperatures were obtained. Estimates of heat absorption, evaporation, and changes in horizontal heat content (advection) for clear, partly cloudy, and cloudy skies were derived from these mean temperatures. The ocean was assumed to be neither gaining nor losing heat during this season of the year. For clear skies, evaporative heat loss exceeded long-wave (back radiation) heat loss; for cloudy skies, condensation resulted in a net gain of heat. Hourly mean temperatures and temperature gradients are presented. Surface temperature was changed about 0.1° F by evaporative heat flux and a comparable amount by horizontal heat flux.

FOREWORD

Effective thermal structure predictions for the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) of the U.S. Naval Oceanographic Office require knowledge of heat transfer processes. To investigate such processes, the Oceanographic Office conducted a series of 16 experiments in the Atlantic and Pacific Oceans between 1958 and 1965. The processes governing the daily and annual cycle of temperature in the upper layers of the ocean were measured during these experiments. The results of an experiment in September 1959 at Ocean Weather Station ECHO (35°N, 48°W) are discussed in this report. Diurnal temperature changes recorded during this experiment have been analyzed by the author in Technical Report No. 132.

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CONTENTS

Page

INTRODUCTION 1

HEAT BUDGET CALCULATIONS 2

RADIATION DATA 2

HORIZONTAL AND VERTICAL HEAT EXCHANGE UNDER CLEAR SKIES. 6

HORIZONTAL AND VERTICAL HEAT EXCHANGE UNDER PARTLY CLOUDY SKIES. . 11

HORIZONTAL AND VERTICAL HEAT EXCHANGE UNDER CLOUDY SKIES 13

EFFECTS OF CLOUDINESS ON THE THERMAL STRUCTURE 15

SUMMARY AND DISCUSSION 19

REFERENCES 23

APPENDIX
Appendix A. Observed and Fitted Mean Temperatures. 25

TABLES
Table 1. Incoming and Reflected Radiation at OWS ECHO. 4
Table 2. Mean Radiation for Various Cloud Coverage 5
Table 3. Net and Absorptive Heat Changes for Clear Skies . . . 7
Table 4. Calculation of Hourly Horizontal and Vertical Heat Exchange for Clear Skies. 9
Table 5. Net and Absorptive Heat Changes for Partly Cloudy Skies 11
Table 6. Calculation of Horizontal and Vertical Heat Exchange for Partly Cloudy Skies 11
Table 7. Net and Absorptive Heat Changes for Cloudy Skies. . . 13
Table 8. Number of BT Observations 15

ILLUSTRATIONS
Figure 1. Shipboard Radiation Mount 3
Figure 2. Estimated Hourly Heat Exchange. 6
Figure 3. Absorptive Heat Exchange for Clear Skies. 8
Figure 4. Average Heat Exchange for Clear Skies 10
Figure 5. Average Heat Exchange for Partly Cloudy Skies . . . 12
Figure 6. Average Heat Exchange for Cloudy Skies. 14
Figure 7. Surface Temperature for Various Cloud Amounts . . . 16
Figure 8. Average Air-Sea Temperature Differences 17
Figure 9. Average Temperature at 20 Feet. 18
Figure 10. Average Temperature Gradients 20
Figure 11. Average Temperature Gradients 21
Figure 12. Mean BT's for Various Cloud Codes 22

INTRODUCTION

The U.S. Naval Oceanographic Office (NAVOCEANO) is investigating thermal changes in the ocean as part of its various operational commitments connected with oceanographic prediction. Specifically, the air-sea interface portion of the thermal structure was studied some years ago in relation to wave forecasting, because thermal stability of the layer of air near the ocean surface was believed to affect prediction of wave heights. For this purpose, daily synoptic charts of air-sea temperature difference and thermal gradients in the ocean were constructed from 1952 to 1953. The impetus for this investigation resulted from a theoretical study of the effects of weather on the thermal structure of the ocean (reference 1).

These preliminary studies resulted in a multi-ship experiment during June and July 1953 by the USS SAN PABLO (AGS-30) and the USS REHOBOTH (AGS-50) which were anchored for periods of time on a seamount northeast of Bermuda. A report concerning internal temperature fluctuations observed during that cruise (Operation STANDSTILL) was published by NAVOCEANO (reference 2). More recently, reflectivity of the ocean was investigated by Olson (reference 3) using solar radiation measurements from this operation.

The specific observational technique initiated on Operation STANDSTILL (BT measurement every 30 minutes) was followed during research experiments conducted in support of Antisubmarine Warfare Environmental Prediction Services (ASWEPS). Abundant BT data existed for the various United States weather ships; however, these data were collected at varying time intervals and contained many gaps. In order to compare the existing data with observations made at fixed 30-minute intervals, a series of experiments was conducted at Ocean Weather Station ECHO (35°N, 48°W) with the cooperation of the U.S. Coast Guard. These experiments were conducted from 8 to 29 November 1958, 28 February to 16 March 1959, 20 May to 8 June 1959, and 2 to 21 September 1959.

The ECHO cruises were designed to sample the thermal structure during all seasons: November represented a season of rapid cooling of the upper oceanic thermal structure; May-June, a period of warming; February-March, a winter situation; and September, a late summer situation. The thermal structure in winter is characterized by convection to depths of 600 feet or more, so that studies of heat budget characteristics are affected by vertical motion of the water. In summer, surface heating exerts the major control over the vertical changes, and, thus, daily effects are more prominent. For this reason, the author examined the physical processes readily evident in the diurnal heating cycle at this mid-ocean location (reference 4). A study of some 900 BT's reduced to punchcard readings at 20-foot intervals concluded that convection during nighttime hours reached a depth of 60 feet and that some of the anomalous hourly temperature changes could be explained by stationary internal waves on a very weak thermocline at 60 feet. Salinity data supported this theory.

Reference 4 demonstrated that mean temperatures calculated from BT measurements made at relatively short-time intervals for periods of several days or a few weeks are sufficiently accurate to be used for heat budget calculations, even though individual BT's may contain errors.

HEAT BUDGET CALCULATIONS

The generalized heat budget may be characterized by the relationship

$$Q_s - Q_b - Q_e - Q_h + Q_v + Q_\theta = 0$$

where Q_s = incoming solar radiation

Q_b = back radiation from the sea surface

Q_e = evaporative heat exchange

Q_h = sensible heat exchange

Q_v = heat change due to currents and mixing

Q_θ = local heat change or heat expended in warming or cooling the water.

In past practice, the Oceanographic Prediction Division rearranged this equation to isolate the local heat change as the right-hand term of the equation, thus: $Q_s - Q_b - Q_e - Q_h + Q_v = Q_\theta$. This term was isolated, because the time of year when this term changes from positive to negative is extremely important in making long-range ice predictions. Thus, when the theory of ice potential was developed in 1952 (reference 5), this term was used in determining when oceanographic observations were to be made for predicting winter growth of sea ice.

At the time of the present cruise, Q_θ can be considered to be essentially zero. OWS ECHO is located in an area of relatively homogenous water, and thus Q_v is expected to be small but not necessarily zero.

Radiation data were obtained in September 1959 to supplement the BT data. Albedos of sea and sky deduced from analysis of the radiation and BT data permitted estimation of heat exchange processes of the vertical water column from surface to 100 feet. The details of this calculation form the basis of this report.

RADIATION DATA

Continuous radiation data were obtained with two Eppley pyrheliometers mounted together over the ship's bow. An upright instrument measured total incoming radiation from sun and sky, and an inverted instrument measured radiation reflected from the sea surface. Arrangement of the instrumentation is shown in figure 1. Two radiometers were also mounted with the pyrheliometers. Data were not obtained with the radiometers, however, owing to recorder malfunction. The accuracy of this system is not ideal, because the inverted instruments sometimes observed sea surface shaded by the ship. Radiation data are presented in table 1.

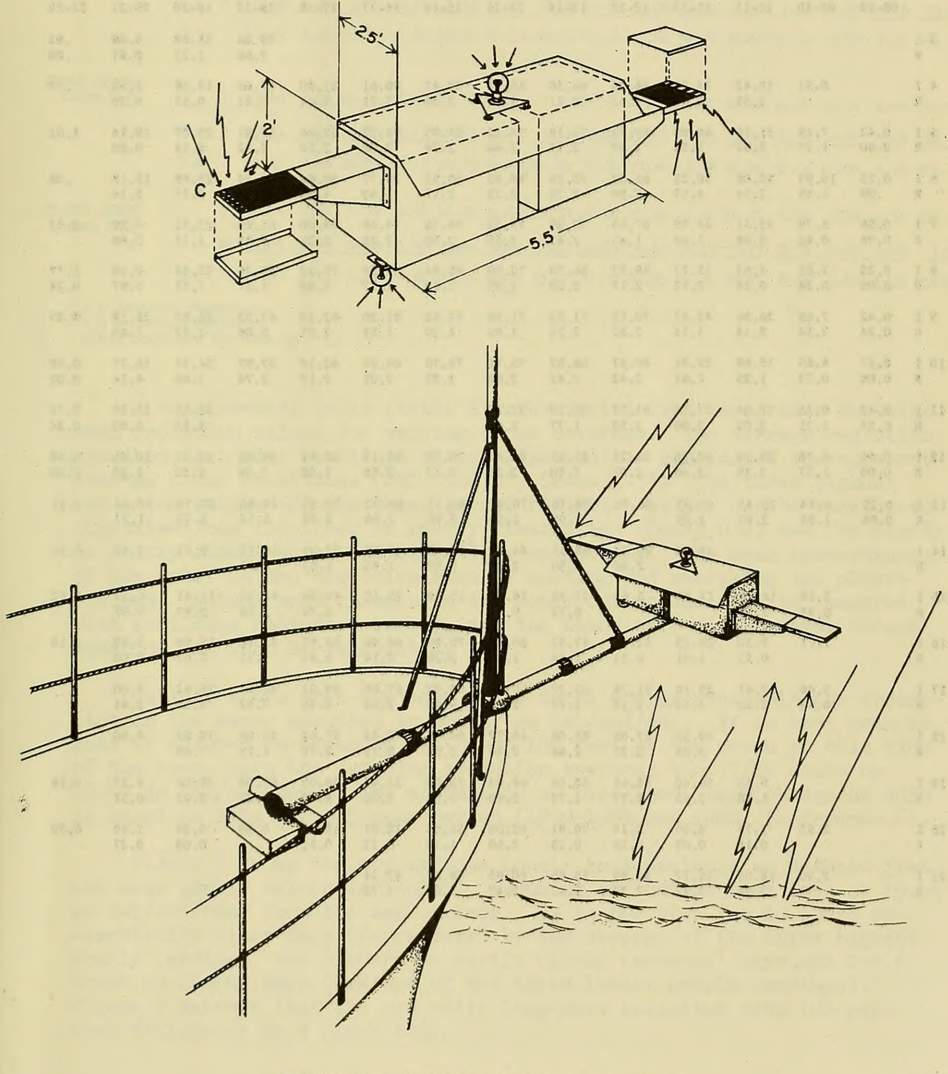

FIGURE I SHIPBOARD RADIATION MOUNT

TABLE 1

INCOMING AND REFLECTED RADIATION AT OWS ECHO, SEPTEMBER 1959
(gm cal/cm^2/hr)

I = Incoming Radiation
R = Reflected Radiation

Date Sept		Hour (Z)													
		08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22
3	I											49.86	33.88	6.68	.93
	R											2.66	1.21	0.81	.00
4	I		0.51	18.42	24.59	46.05	66.50	65.74	70.47	80.61	51.80	47.66	18.08	5.83	.42
	R			1.31	0.81	1.41	0.81	1.81	2.18	1.71	1.61	0.81	0.57	0.20	
5	I	0.42	7.18	31.10	48.00	69.71	73.18	94.13	80.95	76.22	65.66	53.91	29.07	10.14	1.01
	R	0.00	1.29	3.62	2.58	1.69	1.13	2.66	2.74	2.90	2.50	2.42	3.14	0.89	
6	I	0.25	10.99	30.08	30.25	65.32	73.26	89.91	80.53	79.77	58.64	48.24	19.69	13.18	.08
	R	.08	1.85	2.34	4.67	2.90	0.72	2.25	2.17	1.69	1.53	2.01	2.17	3.14	
7	I	0.59	8.79	22.31	44.95	87.63	70.90	77.32	78.25	74.68	64.90	61.09	22.31	6.59	0.42
	R	0.08	0.48	0.48	1.69	1.45	2.42	2.50	2.50	2.25	2.25	4.43	1.13	0.48	
8	I	0.25	1.01	3.63	13.77	59.32	56.70	70.90	80.44	52.56	75.12	30.25	22.48	9.38	1.77
	R	0.08	0.24	0.24	0.72	2.17	2.50	1.05	1.69	1.77	1.69	1.37	1.13	0.97	0.24
9	I	0.42	7.69	26.96	42.67	70.13	71.83	71.99	75.63	81.20	62.19	47.32	26.87	13.18	0.25
	R	0.24	2.34	3.14	3.14	2.82	2.25	1.85	1.29	1.53	2.01	3.06	2.42	1.69	
10	I	0.17	4.65	19.69	29.91	69.37	68.02	75.71	74.70	66.84	62.19	57.97	34.14	16.73	0.59
	R	0.08	0.72	1.29	1.61	2.42	2.42	2.66	2.25	2.01	2.17	2.74	3.06	4.14	0.08
11	I	0.42	9.13	27.04	47.74	61.77	74.19	77.32					35.66	15.80	0.76
	R	0.24	1.21	2.09	2.90	2.58	1.77	1.61					3.22	2.09	0.24
12	I	0.00	6.76	23.24	49.26	53.24	81.97	62.61	78.59	61.18	68.61	46.90	33.12	10.65	0.68
	R	0.00	1.37	3.38	2.66	2.01	2.50	2.25	2.17	2.58	1.05	3.06	3.30	1.85	0.08
13	I	0.25	8.34	25.43	45.63	56.02	78.16	70.81	80.11	66.92	70.39	49.86	32.70	10.48	0.51
	R	0.08	1.93	2.82	2.09		1.05	2.50	2.90	2.66	2.98	3.14	3.95	1.37	
14	I				49.52	49.52	68.11	44.87	35.49	45.55	37.01	19.77	8.51	3.46	0.34
	R					2.50	2.50	2.01	1.37	1.85	1.61	0.81			
15	I		5.15	14.28	11.66	3.63	27.38	18.08	13.18	25.10	49.26	41.74	11.41	6.17	0.42
	R		0.48	1.29			0.72	0.24			2.74	2.34	0.97	0.97	
16	I		2.11	9.30	28.29	32.17	47.32	60.37	70.30	68.96	63.97	41.10	15.58	5.49	0.10
	R			0.23	1.01	0.91	1.46	1.46	2.28	2.14	1.82	1.31	2.92	0.00	
17	I		3.46	17.41	39.10	31.74	65.22	50.04	63.02	67.06	59.01	40.01	25.61	7.60	
	R		0.32	2.22	2.32	1.18	2.17	3.14	5.40	2.58	3.35	3.82	3.52	1.41	
18	I				39.55	47.08	48.06	46.77	64.35	70.43	57.62	35.06	19.82	4.80	
	R				3.08	2.23	2.88	2.46	2.94	3.11	2.75	1.18	1.09		
19	I			9.35	28.40	58.68	65.64	64.44	73.63	51.44	39.00	43.06	29.06	8.17	0.16
	R			1.88	2.53	1.72	1.77	2.40	2.91	2.30	1.42	3.27	2.01	0.31	
20	I		2.33	1.74	4.50	3.14	20.91	62.00	35.54	12.01	18.18	6.59	5.24	2.40	0.70
	R			0.18	0.09	0.28	0.25	2.60	1.19	0.22	0.52		0.09	0.27	
21	I		2.90	18.05	35.12	52.89	55.85	60.95	58.62	47.21					
	R			2.34	3.12	2.39	1.47	2.47	3.04	1.72					

TABLE 2

MEAN RADIATION FOR VARIOUS CLOUD COVERAGE
(gm cal/cm^2/hr)

		HOUR (Z)														
		08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	TOTALS
MEAN CLOUDINESS (Code 3-5)	I	0.31	5.40	18.63	34.05	50.97	61.84	61.26	65.52	60.46	56.47	42.38	23.51	8.71	0.57	490.08
	R	0.10	1.11	1.80	2.19	1.92	1.71	2.11	2.44	2.06	2.18	2.40	2.11	1.22	0.16	23.51
	I-R	00.21	4.29	16.83	31.86	49.05	60.13	59.15	63.08	58.40	54.29	39.98	21.40	7.49	0.41	466.57
CLEAR SKIES (Code 0-2)	I	0.48	9.64	29.41	48.93	75.82	78.11	87.12	80.64	80.53	71.37	57.66	34.56	15.24	1.24	670.75
	R	0.11	1.18	2.68	2.63	2.99	1.77	2.47	2.20	1.64	1.91	3.20	2.50	2.64	0.08	28.00
	I-R	0.37	8.46	26.73	46.33	72.83	76.34	84.65	78.44	78.89	69.46	54.46	32.06	12.60	1.16	642.75
CLOUDY SKIES (Code 6-8)	I	0.14	1.61	4.89	9.98	12.84	31.87	36.56	28.07	27.55	31.40	28.87	8.39	3.89	0.11	226.18
	R	0.05	0.08	0.22	0.40	0.49	0.82	1.57	0.85	0.69	1.18	0.73	0.35	0.09	0.00	7.52
	I-R	0.09	1.53	4.67	9.58	12.35	30.05	35.00	27.22	26.86	30.22	28.14	8.04	3.80	0.11	218.66

I = Incident radiation
R = Reflected radiation
Cloud Codes are WMO Code 60

A supplemental table (table 2) constructed from these data contains mean radiation values for varying cloud coverage. The average radiation received each hour (incident minus reflected) is considered to represent average cloud conditions (WMO Code 60, Codes 3-5). The three highest radiation values and the three lowest radiation values can be considered approximations for clear or nearly clear skies (Codes 0-2) and for cloudy or nearly cloudy skies (Codes 6-8), respectively. The mean temperatures of the water column are calculated by sorting and averaging the observations. Actual heat changes in the water column can then be compared with available radiative energy, and the other terms in the heat budget equation can then be calculated.

Table 2 shows that the mean daily total energy available for absorption in the water amounted to 466.57 gm cal/cm^2/day. If no heat gain or loss is assumed to occur in the upper 100 feet of the ocean at this time of the year, then the outgoing radiation averages 466.57/24 hours or 19.44 gm cal/cm^2/hour. The assumption of zero local heat change at ECHO is based on data for a 5-year period (1950-1954 and 1960) (reference 6).

Figure 2 shows the approximate hourly heat exchange as deduced from the mean hourly values in table 2, assuming a constant heat loss of 19.44 gm cal/cm^2/hour from the sea surface. Q_θ is positive for 10 hours on essentially clear days (represented by the average of the three highest hourly readings) for 9 hours on partly cloudy (average) days and for 6 hours on cloudy days (average of the three lowest hourly readings). Figure 2 assumes that the sea emits long-wave radiation with 100-percent efficiency as a black body.

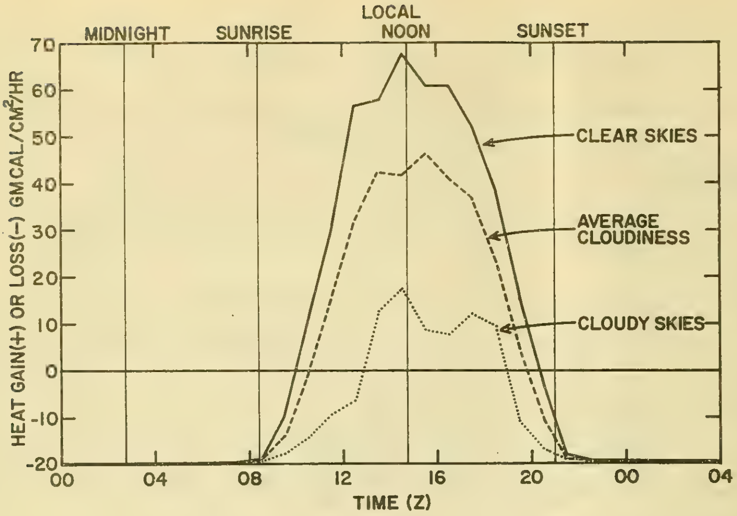

FIGURE 2 ESTIMATED HOURLY HEAT EXCHANGE

HORIZONTAL AND VERTICAL HEAT EXCHANGE UNDER CLEAR SKIES (CLOUD CODE 0-2)

In developing NAVOCEANO's computer programs for predicting temperature changes in the upper 100 feet of the ocean (reference 7), the various parameters involved in the heat budget must be closely evaluated and examined. A previous report on ECHO by the author (reference 4) describes an estimate of the coefficient of thermal conductivity based on BT observations. The values for heat absorption in sea water are now examined.

To transform temperature changes into heat equivalent, the following procedures have been used. The total heat change in a nominal water column 1 cm^2 in cross section appears as a change in mean temperature of the water column. Thus, for a change in temperature, ΔT, the heat equivalent is

$$\Delta Q = \rho c_p h \, \Delta T,$$

where ΔQ = heat change (gm cal/cm^2)

ρ = density of the water column (gm/cm3)

c_p = specific heat (cal/gm)

h = thickness of the water layer.

In this study the following values have been used:

ρ = 1.0242 gm/cm3, corresponding to a mean temperature of 25.3°C and a mean salinity of 36.25°/oo as used in reference 4,

$c_p = 0.931$ cal/gm, and

$h = 20$ ft (609.6 cm).

For these values, a change of 0.1°F in mean temperature of a layer 20 feet thick is equivalent to a heat gain or loss of 32.292 gm cal/cm^2.

Individually measured hourly heat changes in the water do not balance, because the measured changes are the result of several factors acting simultaneously, such as evaporation, condensation, sensible heat change, mechanical mixing, convection, conduction, and horizontal transport (advection). Sufficiently lengthy observation periods appear necessary for minimizing the effects of these processes.

TABLE 3

NET AND ABSORPTIVE HEAT CHANGES FOR CLEAR SKIES (Cloud Code 0-2)
(gm cal/cm^2/hr)

Hour (Z)	Net Radiation Budget	Net Measured Heat Change					Measured Absorptive Heat Change					
		0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	TOTALS
10-11	7.29	-4.84	-8.07	-8.07	-9.67	-14.53	1.61	1.61	-1.61	3.23	1.61	6.45
11-12	26.89	12.92	8.07	6.46	6.46	4.84	3.23	1.61	0.00	0.00	1.61	6.45
12-13	53.39	32.29	24.22	22.60	24.22	24.22	6.46	1.61	0.00	-1.61	1.61	8.07
13-14	56.90	48.44	38.75	32.29	30.68	33.91	6.46	3.23	3.23	-1.61	-1.61	9.70
14-15	65.21	58.13	46.82	35.52	32.29	38.75	6.46	4.84	6.46	-3.23	-3.23	11.30
15-16	59.00	54.90	41.98	30.68	27.45	32.29	6.46	6.46	4.84	-1.61	-3.23	12.92
16-17	59.45	43.59	32.29	20.99	16.15	17.76	4.84	6.46	4.84	0.00	-1.61	14.53
17-18	50.02	27.45	17.76	6.46	1.61	0.00	1.61	8.07	3.23	1.61	0.00	14.52
18-19	35.02	4.84	-1.61	-11.30	-14.53	-17.76	-1.61	8.07	1.61	1.61	1.61	11.29
19-20	12.62	-16.15	-17.76	-20.99	-24.22	-30.68	-3.23	4.84	-1.61	4.84	1.61	6.45
TOTALS for 10-20Z	425.79	261.57	182.45	114.64	90.44	88.80	32.29	46.80	20.99	3.23	-1.63	101.68
20-21										3.23	3.23	
21-22										1.61	3.23	
22-23										1.61	1.61	
23-00										1.61	-3.23	
00-01										-3.23	-3.23	

↑ incident radiation at the surface.

— actual measured changes in heat stored in the water — [illegible]

Some sort of absorption based upon ΣT. (??)

Table 3 presents net and absorptive heat changes in the water calculated from fitted mean temperature curves. The data used in preparing this table are presented in appendix A. This table gives the hourly changes in the various layers and the computed absorption. The method of deriving the mean temperature curves is discussed below. Conduction (eddy and molecular) obviously plays a major role in distribution of absorbed thermal energy on an hourly basis. If the hourly changes in table 3 are plotted (figure 3), the time lag and diminution of heating with depth are clearly portrayed. However, if the hourly heat changes are totaled or, alternately, if the total heat changes for the hours when Q_θ is positive are calculated, the phenomenon of absorption is more easily explained.

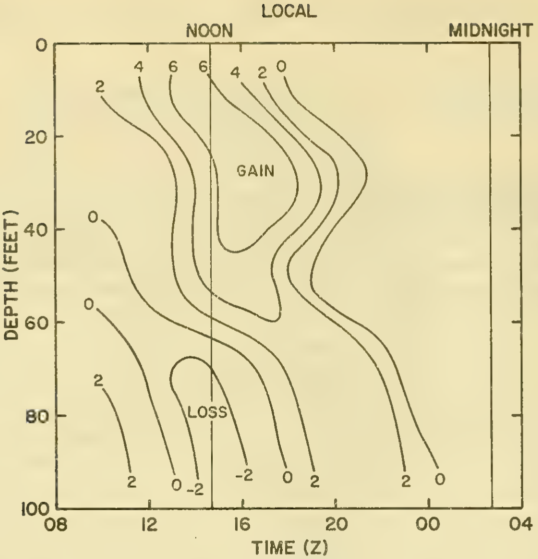

FIGURE 3 ABSORPTIVE HEAT EXCHANGE FOR CLEAR SKIES (CLOUD CODE 0-2)(GM CAL/CM²/HR)

Table 3 shows 425.79 gm cal/cm^2 of radiation available for absorption in the 10 hours between 1000Z and 2000Z, whereas the heat changes measured in the various layers amounted to 261.57, 182.45, 114.64, 90.44, and 88.80, or a net value of 737.90 gm cal/cm^2. The measured values represent some heat that was measured more than once; as heat changes progressed downward, they were recorded in a given layer at one time and in another layer at a later time. In addition, the measured values include short-term horizontal and vertical motion. Therefore, the measured values are of little use in determining total absorption. Absorption in a layer appears as a change in temperature gradient within the layer. By calculating the changes in gradient, the hourly absorption values are found and presented in table 3.

The first step in determining horizontal and vertical heat transport is to subtract the absorption from the net measured heat changes. Table 4 shows the results. The first five columns of table 4 contain the net heat changes after removal of absorption. Table 3 gives the amount of radiation available for absorption. Using the values of table 27 of Sverdrup, Johnson, and Fleming (reference 8), adjusted to 20-foot layers, 82.70 percent of the radiation should be absorbed in the layer from 0 to 20 feet; 8.68 percent in the layer 20-40 feet; 4.90 percent in the layer 40-60 feet; 1.52 percent in the layer 60-80 feet; and 1.00 percent in the layer 80-100 feet. Subtracting the appropriate percentage of the net radiational budget from the left columns of table 4, the remaining values of horizontal plus evaporative and sensible heat change are found in the right columns of table 4. This procedure is allowable, because heat exchange is calculated only for daylight hours, so that effects of convection are effectively eliminated. The assumption has been made that the coefficient of absorption given in reference 8 is accurate for the mid-Atlantic data used in this report.

TABLE 4

CALCULATION OF HOURLY HORIZONTAL AND VERTICAL HEAT EXCHANGE FOR CLEAR SKIES ($gm\ cal/cm^2/hr$)

Hour	Net After Removal of Absorption					Horizontal Plus Evaporative and Sensible Heat Exchange					$\bar{Q}_h$	Q_e+Q_θ
(Z)	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'		
10-11	-6.45	-9.68	-6.46	-12.90	-16.14	-12.48	-10.31	-6.82	-13.01	-16.21	-11.59	-0.89
11-12	9.69	6.46	6.46	6.46	3.23	-12.55	4.13	5.14	6.05	2.96	4.57	-17.12
12-13	25.83	22.61	22.60	25.83	22.61	-18.32	17.98	19.98	25.02	22.08	21.26	-39.58
13-14	41.98	35.52	29.06	32.29	35.52	-5.08	30.58	26.27	31.43	34.95	30.81	-35.89
14-15	51.67	41.98	29.06	35.52	41.98	-2.26	36.32	25.86	34.53	41.33	34.51	-36.77
15-16	48.44	35.52	25.84	29.06	35.52	-0.35	30.40	22.95	28.16	34.93	29.11	-29.46
16-17	38.75	25.83	16.15	16.15	19.37	-10.42	20.67	13.24	15.25	18.78	16.98	-27.40
17-18	25.84	9.69	3.23	0.00	0.00	-15.53	5.35	0.78	-0.76	-0.50	1.22	-16.75
18-19	6.45	-9.68	-12.91	-16.14	-19.37	-22.51	-12.72	-14.63	-16.67	-19.72	-15.94	-6.57
19-20	-12.92	-22.60	-19.38	-29.06	-32.29	-23.36	-23.70	-20.00	-29.25	-32.42	-26.34	2.98
										TOTALS	84.59	-207.45

The horizontal, evaporative, and sensible heat exchange is rather easily separated into horizontal and vertical components. The vertical component of evaporative and sensible heat exchange will affect only the layer from 0 to 20 feet, whereas horizontal heat exchange is expected to affect all layers nearly equally. An estimate of the horizontal heat exchange is easily derived by averaging the heat exchange for the four layers from 20 to 100 feet and is given in the column labeled $\bar{Q}_h$. The near equality of the values averaged is the argument to support the accuracy of the absorption coefficient. Extending this value into the layer 0 to 20 feet, the amount of evaporative and sensible heat exchange is given in the extreme right column of table 4. The heat exchange values are shown in figure 4. Horizontal heat exchange per 20-foot layer is generally positive and of the same order of magnitude as vertical heat exchange. The total evaporative-sensible heat loss during the 10-hour period is 207.4 gm cal/cm^2, but the total horizontal heat exchange between 0 and 20 feet is only 84.59 gm cal/cm^2 because the direction of horizontal flow changes from output to input during the 10-hour period.

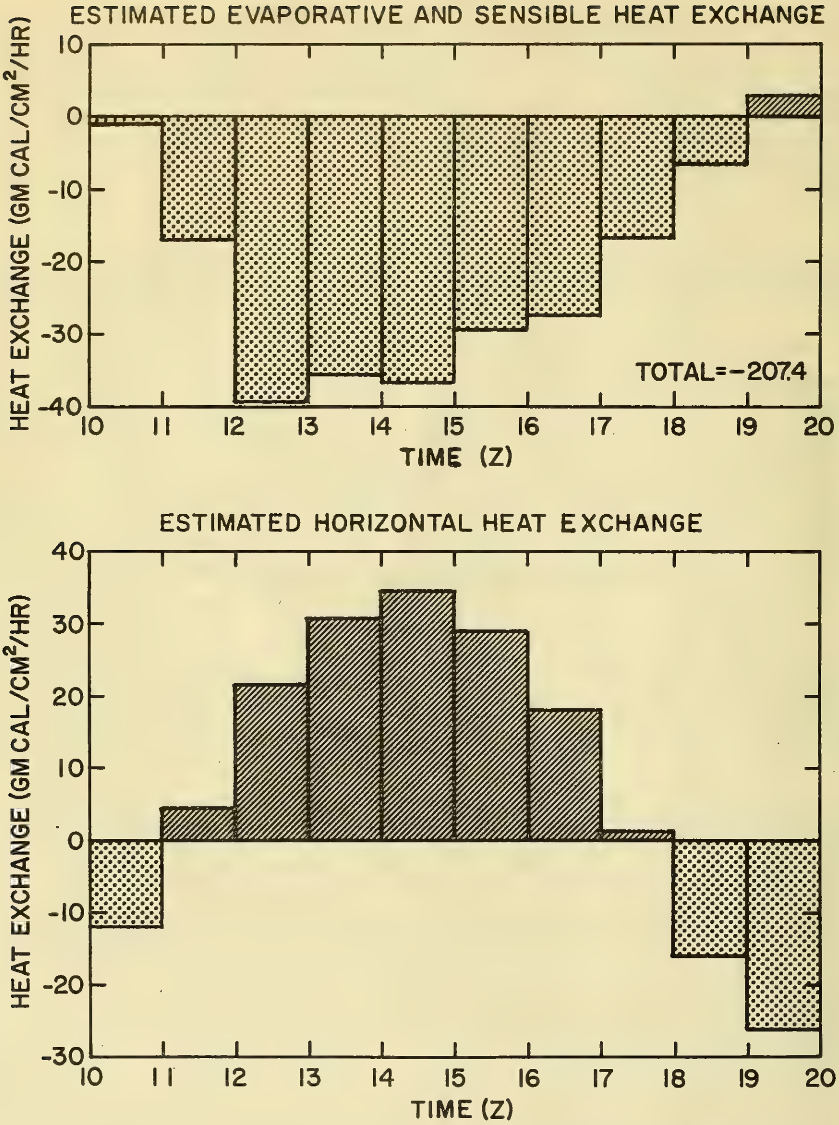

FIGURE 4 AVERAGE HEAT EXCHANGE FOR CLEAR SKIES (CODE 0-2)

HORIZONTAL AND VERTICAL HEAT EXCHANGE UNDER PARTLY CLOUDY SKIES (CLOUD CODE 3-5)

Calculation of horizontal and vertical components of heat exchange under partly cloudy skies is similar to that described above. The results are shown in tables 5 and 6. The radiational budget indicates that heat is available for absorption between 1100Z and 2000Z. In table 6 the horizontal heat exchange values for the layer 0 to 20 feet are larger than the vertical heat exchange totals. The horizontal

TABLE 5

NET AND ABSORPTIVE HEAT CHANGES FOR PARTLY CLOUDY SKIES (Cloud Code 3-5) (gm cal/cm^2/hr)

Hour (Z)	Net Radiation Budget	Net Measured Heat Change					Measured Absorptive Heat Change					TOTALS
		0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	
11-12	12.42	45.21	38.75	32.29	27.45	27.45	3.23	3.23	3.23	1.61	-1.61	9.69
12-13	29.61	45.21	38.75	37.29	25.83	20.99	3.23	3.23	3.23	3.23	1.61	14.53
13-14	40.69	40.36	30.68	20.99	12.92	9.69	4.84	4.84	4.84	3.23	0.00	17.75
14-15	39.71	25.83	17.76	9.69	3.23	-3.23	3.23	4.84	3.23	3.23	-3.23	11.30
15-16	43.64	6.46	-1.61	-8.07	-12.92	-17.76	3.23	-4.84	1.61	3.23	1.61	4.84
16-17	38.96	-14.53	-17.76	-20.99	-22.60	-24.22	1.61	1.61	1.61	0.00	1.61	6.44
17-18	34.85	-27.45	-29.06	-30.68	-29.06	-25.83	1.61	0.00	1.61	-3.23	0.00	-0.01
18-19	20.54	-35.52	-33.91	-32.29	-25.83	-20.99	-3.23	1.61	-3.23	-3.23	-1.61	-9.69
19-20	1.96	-38.75	-32.29	-27.45	-20.99	-11.30	-3.23	-3.23	-1.61	-4.84	-4.84	-17.75
TOTALS for 11-20Z	262.38	46.82	11.31	-19.22	-41.97	-45.20	14.52	11.29	14.52	3.23	-6.46	37.10

TABLE 6

CALCULATION OF HORIZONTAL AND VERTICAL HEAT EXCHANGE FOR PARTLY CLOUDY SKIES (Cloud Code 3-5) (gm cal/cm^2/hr)

Hour (Z)	Net After Removal of Absorption					Horizontal Plus Evaporative and Sensible Heat Exchange					$\bar{Q}_h$	Q_e+Q_θ
	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'		
11-12	41.98	35.52	29.06	25.84	29.06	31.71	34.44	28.45	25.65	28.94	29.37	2.34
12-13	41.98	35.52	34.06	22.60	19.38	17.49	32.95	32.61	22.15	19.08	26.70	-9.21
13-14	35.52	25.84	16.15	9.69	9.69	1.87	22.31	14.16	9.07	9.28	13.70	-11.83
14-15	22.60	12.92	6.46	0.00	0.00	-10.24	9.47	4.51	-0.60	-0.40	3.24	-13.48
15-16	3.23	3.23	-9.68	-16.15	-19.37	-32.86	-0.56	-11.82	-16.81	-19.81	-12.25	-20.61
16-17	-16.14	-19.37	-22.60	-22.60	-25.83	-48.36	-22.75	-24.51	-23.19	-26.22	-24.17	-24.19
17-18	-29.06	-29.06	-32.29	-25.83	-25.83	-57.88	-32.08	-34.00	-26.36	-26.18	-29.66	-28.22
18-19	-32.29	-35.52	-29.06	-22.60	-22.60	-49.28	-37.30	-30.07	-22.91	-22.81	-28.27	-21.01
19-20	-35.52	-35.52	-25.84	-16.15	-6.46	-37.14	-35.69	-25.94	-16.18	-6.48	-21.07	-16.07
										TOTALS	-42.41	-142.28

heat exchange turns from strongly positive between 1100Z and 1200Z to strongly negative between 1700Z and 1800Z, and the total for the 9-hour period is negative. Evaporative and sensible heat loss totals 142.28 gm cal/cm^2 and thus is about 70 percent as large as the evaporative-sensible heat loss under clear skies. The horizontal and vertical heat exchange values are shown in figure 5.

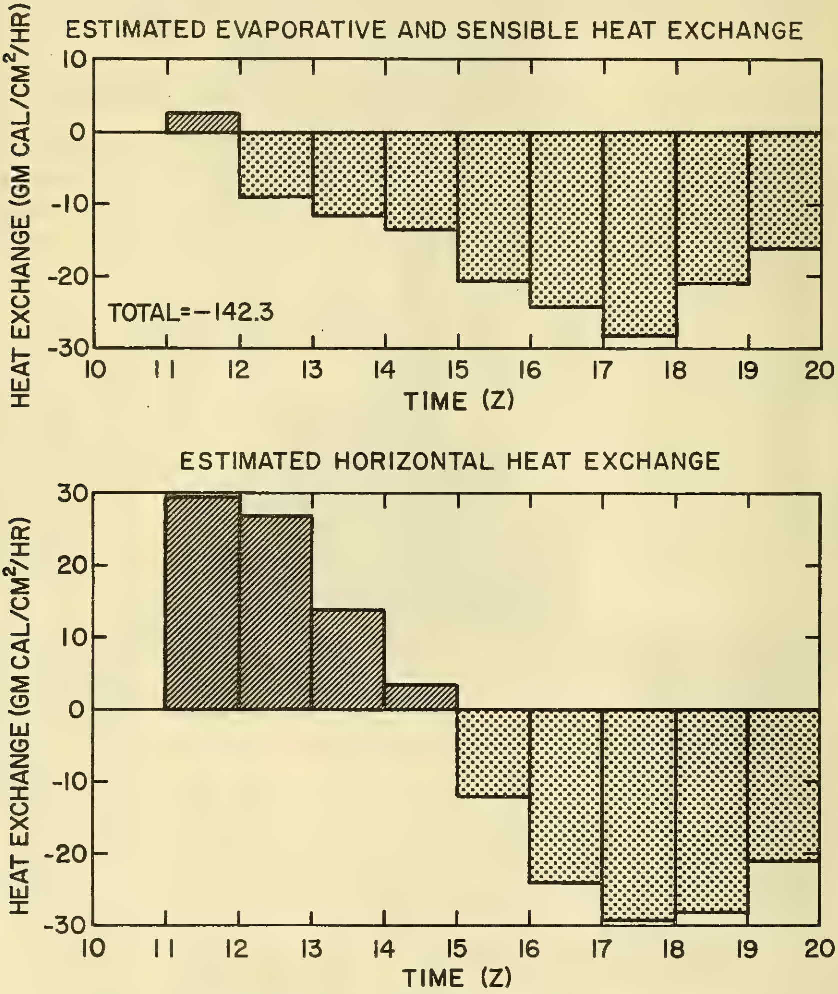

FIGURE 5 AVERAGE HEAT EXCHANGE FOR PARTLY CLOUDY SKIES (CODE 3-5)

HORIZONTAL AND VERTICAL HEAT EXCHANGE UNDER CLOUDY SKIES (CLOUD CODE 6-8)

Calculation of horizontal and vertical heat exchange in the layer 0 to 20 feet for cloudy skies follows the same procedure as that described above. The radiational budget is positive only between 1300Z and 1900Z, and a total of 60.85 gm cal/cm^2 is available for absorption.

TABLE 7

NET AND ABSORPTIVE HEAT CHANGES FOR CLOUDY SKIES (Cloud Code 6-8)
(gm cal/cm^2/hr)

Hour (Z)	Net Radiation Budget	Net Measured Heat Change					Measured Absorptive Heat Change					
		0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	TOTALS
13-14	10.61	-9.69	-14.53	-22.60	-29.06	-29.06	6.46	1.61	-6.46	0.00	0.00	1.61
14-15	15.56	-20.99	-29.06	-40.36	-46.82	-46.82	1.61	6.46	4.84	1.61	-1.61	12.91
15-16	7.78	-25.83	-30.68	-37.14	-45.21	-50.05	3.23	1.61	4.84	3.23	1.61	14.52
16-17	7.42	-17.76	-22.60	-27.45	-32.29	-38.75	1.61	3.23	1.61	3.23	3.23	12.91
17-18	10.78	-1.61	-3.23	-1.61	-4.84	-11.30	1.61	0.00	-1.61	4.84	1.61	6.45
18-19	8.70	16.14	17.76	22.60	22.60	16.14	0.00	-1.61	-3.23	3.23	3.23	1.62
TOTALS for 13-19Z	60.85	-59.74	-82.34	-106.56	-135.62	-159.84	14.52	11.30	-0.01	16.14	8.07	50.02

Hour (Z)	Net After Removal of Absorption					Horizontal Plus Evaporative and Sensible Heat Exchange					$\bar{Q}_h$	$Q_e + Q_\theta$
	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'	0'-20'	20'-40'	40'-60'	60'-80'	80'-100'		
13-14	-16.15	-16.14	-16.14	-29.06	-29.06	-24.92	-17.06	-16.66	-26.22	-29.17	-22.28	-2.64
14-15	-22.60	-35.52	-45.20	-48.43	-45.21	-35.47	-36.87	-45.96	-48.67	-45.37	-44.22	8.75
15-16	-29.06	-32.29	-41.96	-48.44	-51.66	-35.49	-32.97	-42.34	-48.56	-51.74	-43.90	8.41
16-17	-19.37	-25.83	-29.06	-35.52	-41.98	-25.51	-26.47	-29.42	-35.63	-42.05	-33.39	7.88
17-18	-3.22	-3.23	0.00	-9.68	-12.91	-12.14	-4.17	-0.53	-9.84	-13.02	-6.89	-5.25
18-19	16.14	19.37	25.83	19.37	12.91	8.95	18.61	25.40	19.24	12.82	19.02	-10.07
										TOTALS	-131.66	7.08

Table 7 lists the values of heat exchange. Horizontal heat exchange is much larger than vertical heat exchange and is generally negative. Vertical heat exchange (evaporation plus sensible) is positive between 1400Z and 1700Z, indicating net condensation. The total vertical heat exchange is only 7.08 gm cal/cm^2. The heat exchange values are shown in figure 6, which shows strikingly large values of horizontal heat exchange.

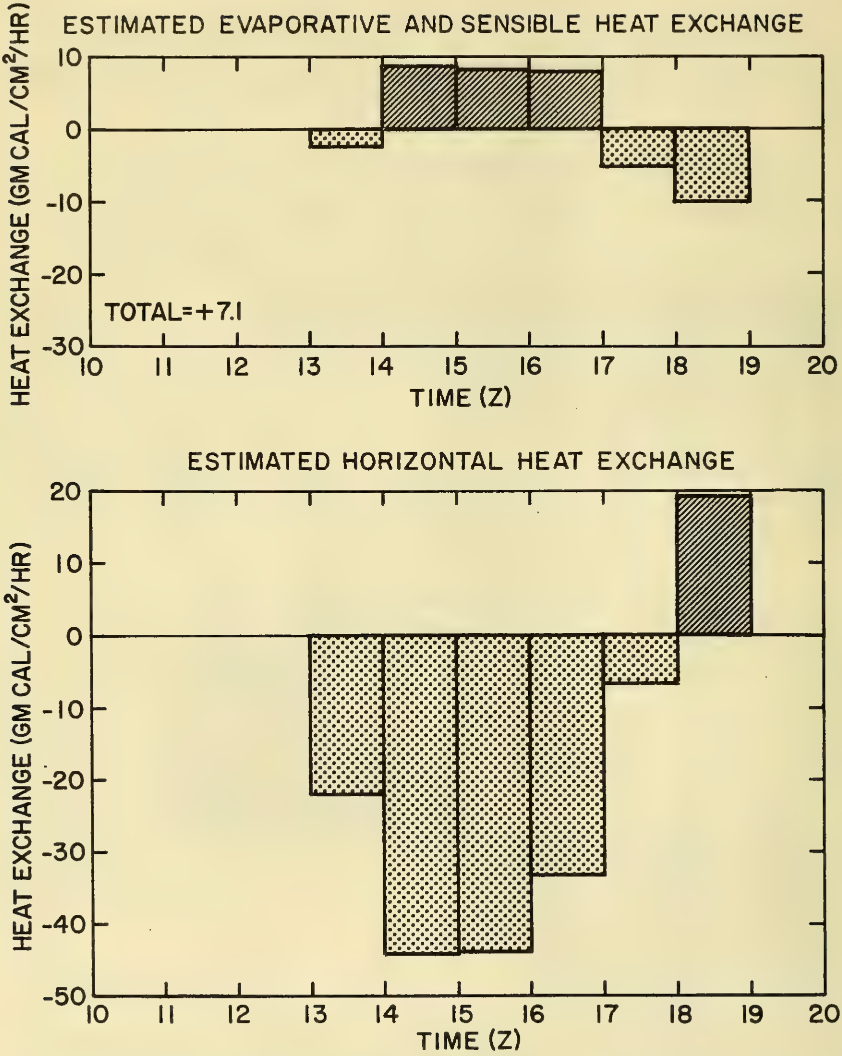

FIGURE 6 AVERAGE HEAT EXCHANGE FOR CLOUDY SKIES (CODE 6-8)

EFFECTS OF CLOUDINESS ON THE THERMAL STRUCTURE

The heat exchange calculations presented above are based on the cloud amount indicated on each BT observation. Of the 901 BT's available for this study, 420 indicated cloud codes 0, 1, and 2 (cloud amount less than 25 percent); 260 had cloud codes 3, 4, and 5 (cloudiness between 25 and 75 percent); and 221 had cloud codes 6, 7, and 8 (cloudiness more than 75 percent). These groups therefore could be considered to represent clear, partly cloudy, and cloudy skies. The number of observations in each group for each hour is listed in table 8. Mean hourly surface temperatures for the three cloud groups are shown in figure 7 along with a fitted curve which represents a Fourier curve with two harmonics. This type of curve is the simplest for portraying multiple peaks and troughs in the daily curve. Average temperatures computed from 10 or less observations generally contain enough uncertainty to make fitting of the curve to match every hourly mean undesirable.

TABLE 8

NUMBER OF BT OBSERVATIONS, 2-21 SEPTEMBER 1959

Hour (Z)	Cloud Code		
	0-2	3-5	6-8
00	19	9	9
01	29	7	10
02	32	6	8
03	20	11	8
04	15	14	6
05	18	13	7
06	16	9	13
07	15	5	14
08	19	8	9
09	19	10	10
10	16	13	7
11	17	12	7
12	17	11	9
13	25	13	12
14	18	16	14
15	19	17	12
16	11	13	6
17	8	14	5
18	11	14	10
19	14	8	10
20	17	8	10
21	17	7	11
22	16	9	9
23	12	13	5
TOTAL	420	260	221

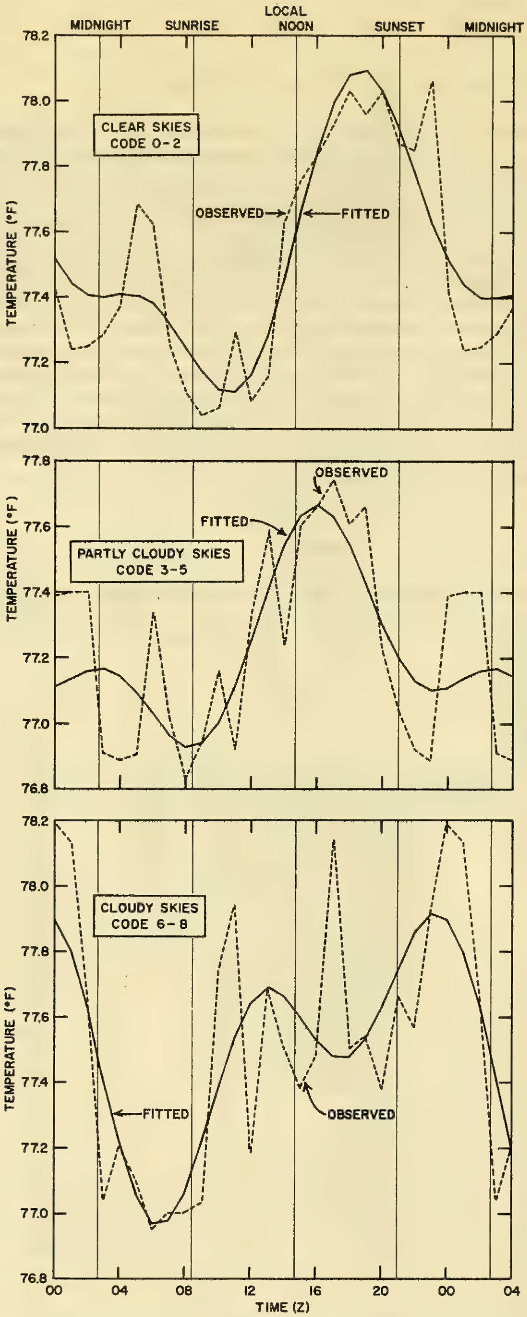

FIGURE 7 SURFACE TEMPERATURE FOR VARIOUS CLOUD AMOUNTS

The fitted mean hourly surface temperatures in figure 7 show that highest temperatures occurred during afternoon hours with nearly clear skies, whereas highest temperatures with cloudy skies were recorded between sunset and midnight. Mean temperatures were almost identical for all cloud types indicating that the data are not biased toward any particular weather condition.

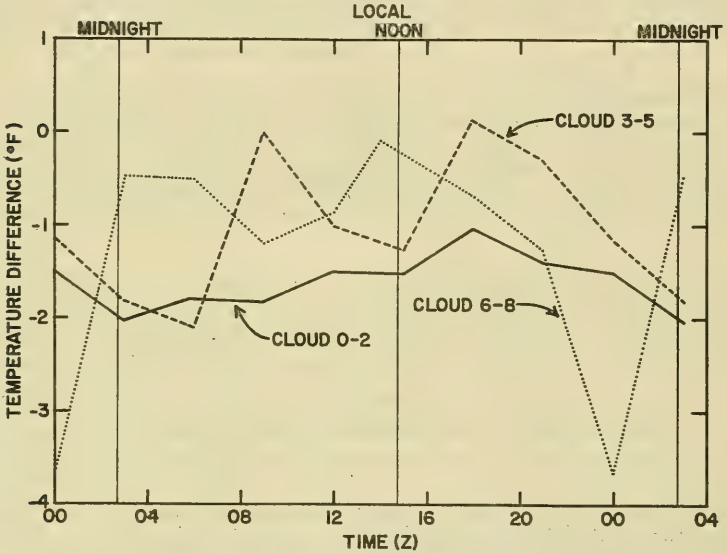

FIGURE 8 AVERAGE AIR-SEA TEMPERATURE DIFFERENCES

Air temperature (figure 8) was only recorded at three-hour intervals. As a result, the air-sea temperature difference observations could not be smoothed and raw means are presented. All but one of the 24 three-hour means were negative indicating that the sea was warmer than the air during this season, as expected. The differences for clear skies are fairly uniform and show a slight diurnal range with least difference in midafternoon. The graph for cloudy skies is more irregular and shows an apparent peak just before noon.

Estimation of the Bowen ratio for the average measured relative humidity of approximately 78 percent indicates that about 6 percent of the total evaporative plus sensible heat exchange was sensible heat, thus 94 percent was evaporative. Evaporation was therefore 0.55 cm/day, based on the values for evaporative and sensible heat exchange given in tables 4, 6, and 7.

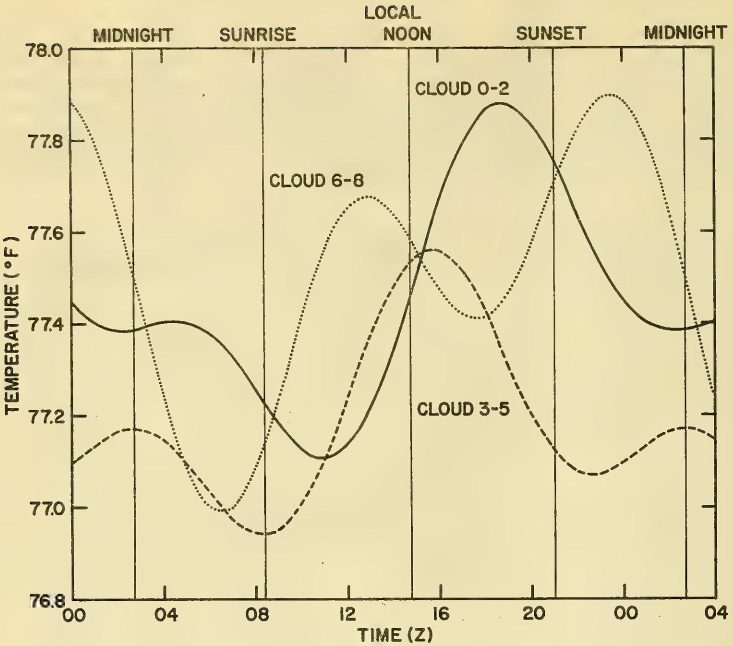

FIGURE 9 AVERAGE TEMPERATURE AT 20 FEET

Figure 9 shows the diurnal changes in temperature at 20 feet for varying cloud amounts. In comparing figure 9 with figure 7, the excess temperature under clear skies is eliminated, and the highest temperature is recorded for cloudy skies after sunset. This figure is presented, because the 20-foot level is removed from the evaporative layer and thus shows radiative effects that are not apparent at the surface. The author has presented elsewhere (reference 9) other reasons for using the 20-foot level as a reference level for surface water temperature, in addition to the fact that the effects of evaporation have been eliminated at the lower level. Referring to the data presented above, the estimated evaporative heat exchange was estimated (from tables 4, 6, and 7) as follows:

Cloud Coverage	Estimated Hourly Evaporative Plus Sensible Heat Exchange (gm cal/cm^2/hour)	Surface Temperature Equivalent ($^\circ$F)
0-2	-20.74	0.13
3-5	-15.81	0.10
6-8	1.18	-0.01

The temperature equivalents are derived by considering the temperature of the layer between the surface and 20 feet to be affected by the evaporative heat change at the surface; but, since all temperature changes associated with heat exchange are concentrated at the surface, the temperature change is doubled there. If the above temperature equivalents are added to or subtracted from the surface temperatures in figure 7 or if the hourly evaporative plus sensible heat exchange values are corrected for the Bowen ratios, the resultant corrected sea surface temperature would demonstrate the great amount of heating which occurs under clear sky conditions.

The effects of evaporation in the 0- to 20-foot layer are graphically shown in figure 10. This figure shows the diurnal changes in the temperature gradients in the layers 0 to 20 feet and 20 to 40 feet. Although temperature gradients in the layer 0 to 20 feet are correlated with cloud amount, the large amount of evaporation under clear skies makes the gradients in the layer 20 to 40 feet even more striking.

Temperature gradients in the layers 40 to 60 feet and 60 to 80 feet, shown in figure 11, indicate decreased diurnal heating effects with depth. They also show the pattern of stationary internal waves shown in reference 4.

Figure 12 illustrates average BT traces for each of the varying amounts of cloud cover. These traces differ greatly in gradient, with very stable conditions prevailing under clear skies and moderate instability under cloudy skies. Sound transmission loss owing to the "afternoon" or "surface" effect is related to these differences in gradients. Under clear skies, the "surface" effect may have lasted as long as 13 hours while under cloudy skies a weak surface effect may have developed for three hours (based on gradients in the layer 20 to 40 feet, where sonar transducers are located).

SUMMARY AND DISCUSSION

Availability of solar radiation data and voluminous BT data at OWS ECHO in September 1959 allowed estimation of the amounts of heat absorption, evaporative-sensible heat exchange, and horizontal heat movement into the water column. Theoretical absorption values permit evaluation of reasonable values of evaporative, sensible, and horizontal heat exchange.

Evaporation was calculated to be 0.55 cm/day. This figure seems reasonable by comparison with results of other investigators. Evaporation lowers the mean sea surface temperature by about 0.1°F. Evaporative heat loss reduces temperature gradients in the layer 0 to 20 feet as much as 0.5°F/100 feet during daylight hours. Thus, the diurnal temperature range at the 20-foot level is more representative of diurnal changes than are surface temperature changes.

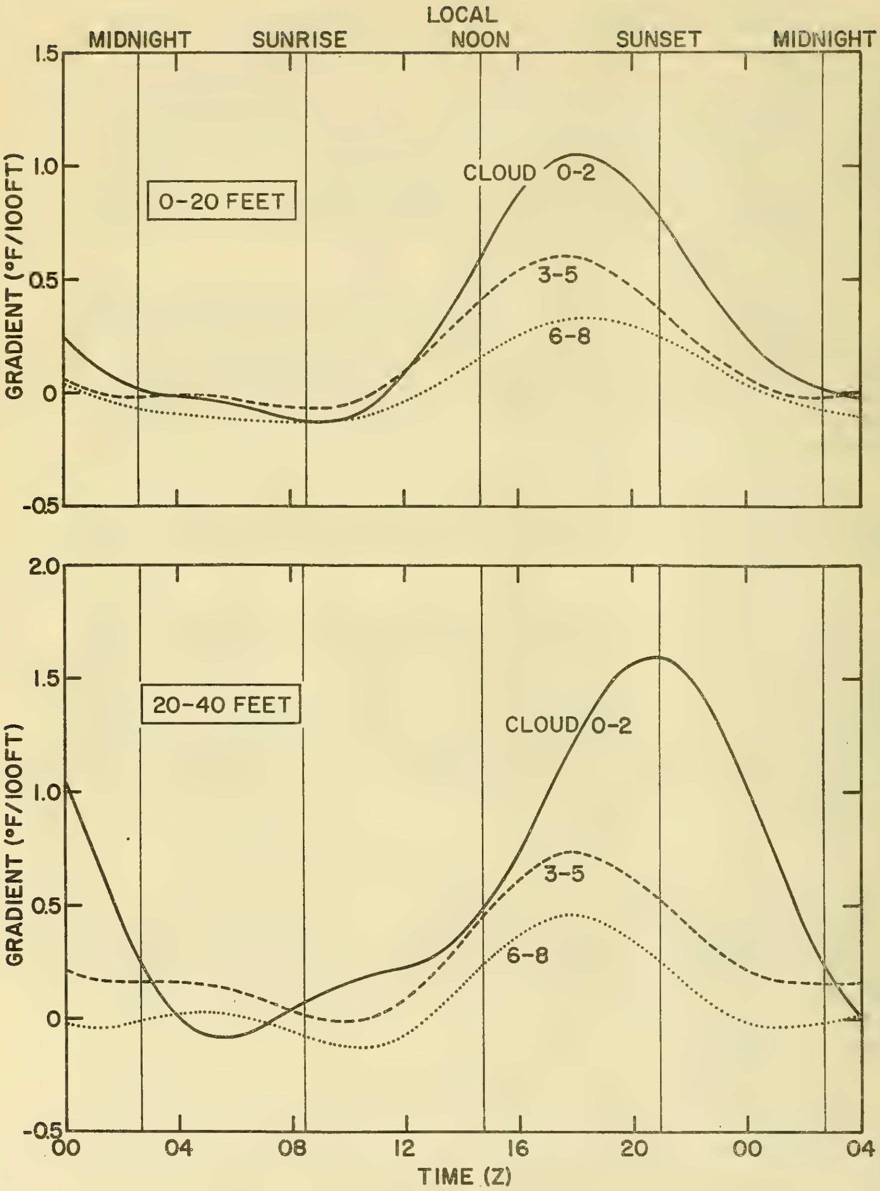

FIGURE 10 AVERAGE TEMPERATURE GRADIENTS

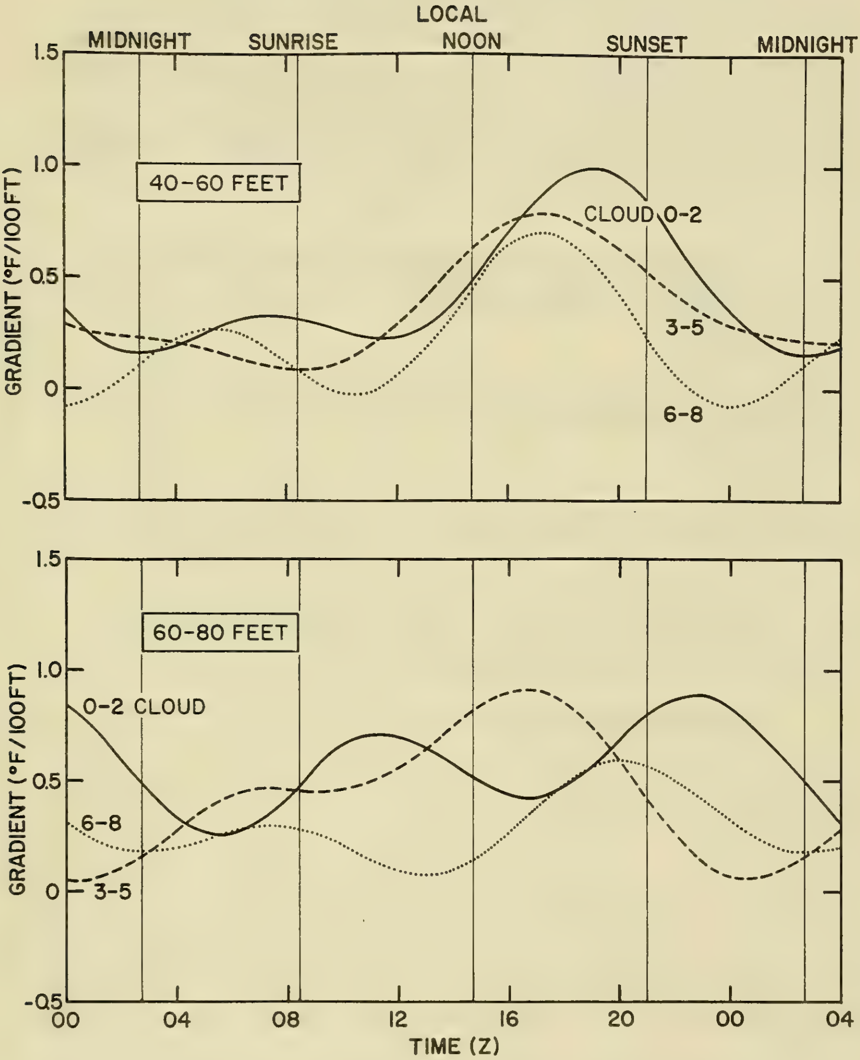

FIGURE 11 AVERAGE TEMPERATURE GRADIENTS

Horizontal heat changes were deduced in the course of the calculation. For clear skies the water column between the surface and 20 feet gained 8.46 gm cal/hour when solar radiation exceeded outgoing radiation; for partly cloudy skies the water column lost heat at the rate of 4.71 gm cal/hour; for cloudy skies the heat loss was 21.94 gm cal/hour. The temperature equivalents of these horizontal fluxes range from 0.015°F/hour to 0.07°F/hour. Thus, horizontal fluxes are of the same order of magnitude as the evaporative heat flux in changing the temperature of the water column.

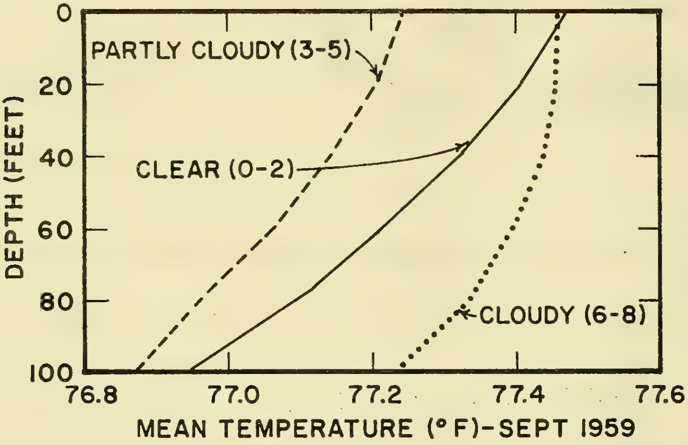

FIGURE 12 MEAN BT's FOR VARIOUS CLOUD CODES

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APPENDIX A

OBSERVED AND FITTED MEAN TEMPERATURES FOR VARIOUS CLOUD COVERAGES

MEAN TEMPERATURES (°F) FOR CLOUD COVER 0-2

	Surface		20 ft		40 ft		60 ft		80 ft		100 ft	
Hour	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted
0000	77.42	77.51	77.38	77.45	77.32	77.25	77.17	77.18	77.03	77.01	76.79	76.79
0100	77.24	77.44	77.18	77.40	77.11	77.26	76.99	77.21	76.86	77.06	76.76	76.86
0200	77.25	77.41	77.22	77.38	77.21	77.30	77.16	77.27	77.03	77.15	76.79	76.96
0300	77.29	77.40	77.28	77.39	77.25	77.35	77.18	77.32	77.11	77.23	76.82	77.07
0400	77.37	77.41	77.39	77.40	77.36	77.40	77.29	77.36	77.17	77.30	77.05	77.16
0500	77.68	77.41	77.67	77.40	77.68	77.42	77.64	77.37	77.61	77.31	77.58	77.20
0600	77.62	77.38	77.64	77.38	77.58	77.40	77.57	77.34	77.53	77.28	77.43	77.18
0700	77.26	77.32	77.27	77.33	77.28	77.34	77.23	77.27	77.16	77.21	77.13	77.10
0800	77.11	77.25	77.11	77.26	77.11	77.25	77.05	77.19	76.96	77.10	76.81	76.99
0900	77.04	77.17	77.03	77.19	76.98	77.17	76.91	77.10	76.85	77.00	76.65	76.86
1000	77.06	77.12	77.07	77.13	77.08	77.10	77.02	77.04	76.85	76.92	76.63	76.76
1100	77.29	77.11	77.30	77.11	77.31	77.07	77.27	77.02	77.05	76.88	76.94	76.71
1200	77.09	77.16	77.10	77.14	77.07	77.09	77.00	77.04	76.95	76.90	76.72	76.72
1300	77.16	77.28	77.05	77.22	77.00	77.16	76.93	77.11	76.81	76.98	76.74	76.79
1400	77.63	77.45	77.56	77.35	77.42	77.27	77.33	77.20	77.21	77.08	77.03	76.90
1500	77.76	77.65	77.66	77.51	77.47	77.40	77.33	77.29	77.22	77.19	76.97	77.03
1600	77.83	77.84	77.62	77.66	77.46	77.51	77.39	77.37	77.26	77.28	77.14	77.14
1700	77.93	77.99	77.70	77.78	77.60	77.59	77.45	77.42	77.41	77.33	77.35	77.20
1800	78.03	78.08	77.77	77.86	77.53	77.62	77.37	77.43	77.26	77.33	77.05	77.20
1900	77.96	78.09	77.78	77.88	77.46	77.59	77.33	77.39	77.22	77.28	77.03	77.14
2000	78.03	78.03	77.86	77.84	77.61	77.52	77.29	77.33	77.15	77.19	77.06	77.04
2100	77.87	77.92	77.68	77.75	77.41	77.43	77.09	77.26	76.95	77.10	76.79	76.93
2200	77.85	77.77	77.79	77.64	77.54	77.34	77.31	77.20	77.13	77.03	76.92	76.84
2300	78.06	77.63	77.90	77.54	77.26	77.28	77.58	77.17	77.36	76.99	77.17	76.79

MEAN TEMPERATURES (°F) FOR CLOUD COVER 3-5

	Surface		20 ft		40 ft		60 ft		80 ft		100 ft	
Hour	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted
0000	77.39	77.11	77.38	77.09	77.31	77.05	77.24	76.99	77.16	76.98	77.03	76.94
0100	77.40	77.13	77.40	77.13	77.37	77.10	77.31	77.04	77.30	77.03	77.27	77.00
0200	77.40	77.16	77.38	77.16	77.37	77.13	77.38	77.08	77.37	77.06	77.43	77.02
0300	76.91	77.17	76.89	77.17	76.85	77.14	76.78	77.09	76.75	77.06	76.78	76.99
0400	76.89	77.15	76.90	77.15	76.88	77.12	76.82	77.07	76.79	77.02	76.72	76.93
0500	76.91	77.10	76.92	77.10	76.92	77.07	76.88	77.03	76.75	76.96	76.45	76.84
0600	77.34	77.03	77.38	77.03	77.32	77.01	77.28	76.98	77.26	76.89	77.18	76.76
0700	77.02	76.97	77.02	76.98	77.00	76.96	76.98	76.93	76.80	76.84	76.60	76.70
0800	76.83	76.93	76.84	76.94	76.84	76.93	76.83	76.91	76.84	76.82	76.75	76.68
0900	76.95	76.94	76.96	76.95	76.94	76.95	76.92	76.93	76.86	76.84	76.81	76.70
1000	77.16	77.00	77.17	77.01	77.19	77.01	77.18	76.98	77.05	76.89	77.01	76.76
1100	76.92	77.11	76.90	77.11	76.89	77.11	76.86	77.07	76.63	76.97	76.27	76.85
1200	77.33	77.26	77.29	77.24	77.25	77.22	77.17	77.16	77.06	77.05	76.96	76.94
1300	77.59	77.41	77.55	77.37	77.55	77.33	77.49	77.25	77.45	77.12	77.35	77.00
1400	77.24	77.55	77.21	77.48	77.15	77.41	77.03	77.30	76.89	77.15	76.88	77.03
1500	77.60	77.64	77.55	77.55	77.44	77.45	77.23	77.32	77.15	77.15	77.03	77.01
1600	77.66	77.67	77.58	77.56	77.42	77.43	77.27	77.29	77.05	77.10	76.86	76.95
1700	77.74	77.63	77.53	77.51	77.50	77.37	77.46	77.22	77.20	77.03	77.02	76.87
1800	77.61	77.55	77.49	77.42	77.21	77.28	77.06	77.12	76.89	76.95	76.64	76.79
1900	77.66	77.43	77.55	77.32	77.36	77.17	77.23	77.03	77.00	76.88	76.83	76.73
2000	77.23	77.30	77.13	77.21	77.13	77.08	76.86	76.95	76.80	76.83	76.79	76.71
2100	77.04	77.20	77.01	77.12	76.91	77.02	76.83	76.91	76.81	76.83	76.79	76.73
2200	76.92	77.13	76.86	77.08	76.81	77.00	76.79	76.91	76.78	76.86	76.74	76.78
2300	76.89	77.10	76.86	77.07	76.73	77.01	76.64	76.94	76.58	76.91	76.40	76.86

MEAN TEMPERATURES (°F) FOR CLOUD COVER 6-8

	Surface		20 ft		40 ft		60 ft		80 ft		100 ft	
Hour	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted	Raw	Fitted
0000	78.19	77.90	78.19	77.89	78.20	77.89	78.22	77.90	78.28	77.84	78.30	77.73
0100	78.13	77.80	78.11	77.80	78.14	77.81	78.19	77.82	78.26	77.77	78.24	77.67
0200	77.66	77.63	77.71	77.64	77.73	77.65	77.71	77.64	77.70	77.60	77.58	77.51
0300	77.04	77.42	77.10	77.44	77.10	77.44	77.06	77.41	77.00	77.38	76.85	77.29
0400	77.20	77.22	77.20	77.24	77.18	77.23	77.18	77.19	77.15	77.15	77.13	77.06
0500	77.10	77.06	77.10	77.08	77.10	77.07	77.06	77.02	77.03	76.97	77.01	76.88
0600	76.95	76.97	76.97	76.99	76.97	76.99	76.93	76.94	76.75	76.88	76.38	76.78
0700	77.00	76.97	77.01	77.00	77.00	77.00	76.97	76.96	76.86	76.90	76.79	76.79
0800	77.00	77.06	77.07	77.09	77.10	77.10	76.97	77.07	76.93	77.01	76.89	76.90
0900	77.03	77.21	77.06	77.24	77.08	77.26	77.08	77.25	77.09	77.19	77.07	77.09
1000	77.74	77.38	77.73	77.40	77.71	77.43	77.70	77.43	77.69	77.39	77.53	77.29
1100	77.94	77.54	77.95	77.55	78.00	77.57	78.07	77.58	78.13	77.55	78.13	77.46
1200	77.18	77.64	77.19	77.65	77.20	77.66	77.21	77.65	77.19	77.63	77.07	77.56
1300	77.68	77.68	77.68	77.68	77.68	77.67	77.62	77.64	77.55	77.62	77.48	77.56
1400	77.51	77.66	77.51	77.64	77.49	77.62	77.42	77.55	77.29	77.53	77.20	77.47
1500	77.38	77.60	77.38	77.57	77.35	77.51	77.30	77.41	77.26	77.38	77.10	77.33
1600	77.48	77.53	77.38	77.48	77.28	77.41	77.08	77.28	77.02	77.23	77.03	77.17
1700	78.14	77.48	78.12	77.42	77.98	77.33	77.76	77.19	77.70	77.12	77.72	77.04
1800	77.50	77.48	77.35	77.41	77.28	77.32	77.19	77.19	77.15	77.09	77.06	77.00
1900	77.54	77.53	77.48	77.46	77.40	77.38	77.34	77.27	77.33	77.15	77.24	77.04
2000	77.38	77.63	77.34	77.57	77.32	77.50	77.25	77.42	77.22	77.30	77.13	77.18
2100	77.66	77.75	77.68	77.70	77.61	77.65	77.57	77.60	77.36	77.49	77.09	77.36
2200	77.57	77.86	77.57	77.82	77.56	77.79	77.61	77.77	77.32	77.67	77.23	77.54
2300	77.92	77.91	77.78	77.89	77.70	77.88	77.56	77.89	77.38	77.80	77.12	77.68

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13. ABSTRACT

Between 2 and 21 September 1959, approximately 900 bathythermograph observations (BT's) were obtained at Ocean Weather Station ECHO (35°N, 48°W). In addition, incoming radiation from sun and sky and reflected radiation from the sea surface were recorded. By grouping the BT data according to cloud amount, mean hourly temperatures were obtained. Estimates of heat absorption, evaporation and changes in horizontal heat content (advection) for clear, partly cloudy, and cloudy skies were derived from these mean temperatures. The ocean was assumed to be neither gaining nor losing heat during this season of the year. For clear skies, evaporative heat loss exceeded long wave (back radiation) heat loss; for cloudy skies, condensation resulted in a net gain of heat. Hourly mean temperatures and temperature gradients are presented. Surface temperature was changed about 0.1°F by evaporative heat flux and a comparable amount by horizontal heat flux.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
OCEANOLOGY OCEAN WEATHER STATIONS OWS ECHO (35°N, 48°W) HEAT TRANSFER TEMPERATURE EFFECT OF CLOUDINESS ON NEAR-SURFACE TEMPERATURES SOLAR RADIATION						

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(PAGE 2)